

Capital Structure, Investment, and Fire Sales

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We study a dynamic general equilibrium model in which firms choose their investment level and capital structure, trading off the tax advantages of debt against the risk of costly default. Bankruptcy costs are endogenous, as bankrupt firms are forced to liquidate their assets, resulting in a fire sale if the market is illiquid. When the corporate income tax rate is positive, firms have a unique optimal capital structure. In equilibrium, firms default with positive probability and their assets are liquidated at fire-sale prices. The equilibrium features underinvestment and is constrained inefficient. In particular there is too little debt and default. (*JEL* D5, D6, G32, G33)

The financial crisis of 2007–2008 and the recent sovereign debt crisis in Europe have focused attention on the macroeconomic consequences of debt financing. In this paper, we turn our attention to the use of debt financing in the corporate sector and study the general equilibrium effects of debt financing on investment and growth. We show that, when markets are incomplete and firms use debt and equity to finance investment, there is underinvestment and debt financing is too low in equilibrium.

At the heart of our analysis is the determination of the firm's capital structure. In the classical model of Modigliani and Miller (1958), capital structure is indeterminate. To obtain a determinate capital structure, subsequent authors appealed to market frictions, such as distortionary taxes, bankruptcy costs, and agency costs.¹ We follow this tradition and examine an environment in which the optimal capital structure balances the tax advantages of debt against the

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¹ See, for example, Barnea, Haugen, and Senbet (1981), Bradley, Jarrell, and Kim (2011), Brennan and Schwartz (1978), Dammon and Green (1987), Fischer, Heinkel, and Zechner (1989), Kim (1982), Leland and Toft (1996), Miller (1977), Titman (1984), and Titman and Wessels (1988).

risk of bankruptcy. More precisely, debt has an advantage over equity because interest payments are deductible from corporate income, whereas dividends and retained earnings are not. At the same time, the use of debt generates the risk of bankruptcy, which the firm perceives as costly because it forces the firm to sell its assets at fire-sale prices. In choosing its capital structure, the firm balances the costs and benefits of debt and equity. We show that these costs and benefits support an interior optimum of the firm's capital structure decision.

We consider an infinite-horizon economy, in which firms choose their production and investment in long-lived capital goods and are subject to productivity shocks. We primarily focus on firms' decisions and abstract from distributional issues by assuming there is a representative consumer. Firms finance the purchase of capital by issuing debt and equity. We assume that markets are incomplete in two respects. First, there are no markets for contingent claims allowing firms to insure against the risk of bankruptcy. Second, when a firm is bankrupt, that is, fails to pay its debtors or to renegotiate its debt, the liquidation of its assets is subject to a finance constraint that causes assets to be sold at fire sale prices, i.e., at less than their fundamental value.

In our model, both the corporate income tax and the cost of bankruptcy represent a pure redistribution of resources rather than a real resource cost for the economy. The corporate income tax revenue is returned to consumers in the form of lump-sum transfers. Similarly, the fire sale of assets constitutes a transfer of value, rather than a deadweight cost, to the shareholders of the firms that buy the assets of bankrupt firms. Because there is a representative consumer, this "redistribution" has no effect on welfare. Nonetheless, a rational, value-maximizing manager of a competitive firm will perceive the tax as a cost of using equity finance and the risk of a fire sale in bankruptcy as a cost of using debt. These private costs determine the firm's financing decisions, act like a tax on capital, and distort the firm's investment decision.

As a baseline, consider the case in which the corporate income tax rate is zero. In the baseline case, the competitive equilibrium allocation is Pareto efficient and the firms' capital structure is indeterminate.² In other words, with a zero corporate income tax rate, the finance constraint never binds and bankruptcy does not result in fire sales. By contrast, when the corporate income tax rate is positive, competitive equilibria have quite different properties. They are not just Pareto inefficient, exhibiting underinvestment, but they are also constrained inefficient. Also, the optimal capital structure of firms is uniquely determined in equilibrium, each firm uses positive amounts of risky debt and equity as sources of finance and faces a positive probability of bankruptcy and fire sales. So many

² To be precise, for each individual firm any combination of debt and equity is optimal. There is however a constraint on the aggregate amount of debt in the economy, that has to be small enough that fire sales do not occur.

features of the equilibrium change when the corporate tax rate becomes positive because the tax interacts with the incompleteness of markets and the finance constraint to endogenously generate private costs of bankruptcy.

The intuition for the second property is simple. If the probability of bankruptcy were zero or if bankrupt firms could be liquidated with no loss of value, then all firms would use 100% debt financing to avoid the corporate income tax. But, in equilibrium, we will show that 100% debt financing is inconsistent with a zero probability of bankruptcy or the absence of fire sales, and is not an optimal decision for firms. A similar argument shows that some debt has to be used in equilibrium. If firms used 100% equity finance, there would be no bankruptcy. Then a single firm could issue a small amount of debt and benefit from the tax hedge, without causing a fire sale. Uniqueness of the optimal capital structure follows from the fact that a rational manager equates the perceived marginal costs of debt and equity financing in equilibrium, and we show that, under reasonable conditions, the marginal costs are increasing.³

The constrained inefficiency of the equilibrium is the result of a pecuniary externality. The tax on equity reduces the return on capital and causes underinvestment in equilibrium. In equilibrium, each firm sets its capital structure so that the benefit of a marginal increase in its debt level, in terms of lower tax paid by the firm, just offsets the increase in private bankruptcy costs.⁴ However, if all firms were to increase their use of debt, the liquidation price of defaulting firms would drop, and hence the profits of any firm buying these assets when solvent increase. This effect offsets the increase in private costs when the firm is bankrupt. As a result, an increase in the debt level of all firms would lower the tax paid and increase the return on capital and hence also investment and welfare. Each firm is a price taker and hence overestimates the costs of debt financing, whereas the planner takes into account the change in prices when all firms increase the use of debt. This is the source of the pecuniary externality. Note that this externality arises even in the presence of a representative consumer. Consumers collectively own all the assets; tax revenues are returned to consumers; and firms hold the same assets after liquidation. Nonetheless, we find that individual firms' decisions are distorted and this imposes a welfare cost on the economy.

As a result of this externality, in the environment considered, there is too little bankruptcy risk and too little debt financing in equilibrium. This appears

³ We do not wish to claim too much for this result, of course. The optimal capital structure is unique only within a given (symmetric) equilibrium. In general, the capital structure depends on the equilibrium, which in turn depends on the model parameters, including policy parameters, such as the tax rate. But note that the Modigliani-Miller theorem also holds for a given equilibrium of a given model.

⁴ The cost of increasing the firm's debt level has two components. First, the probability of going bankrupt and having to liquidate assets in a fire sale increases. Second, the probability of making capital gains when solvent by buying assets of other firms in a fire sale is reduced.

to contradict the common intuition that firms have an incentive to use too much debt. Our analysis shows the importance of a careful evaluation of the costs of firms' default and of the reallocation of assets among them which takes place in this event, illustrating a novel effect of fire sales. The actual costs of default—and hence of debt relative to equity financing—may prove to be lower than the costs perceived by firms, as firms also benefit from this reallocation and the opportunity to acquire assets at low prices, and these prices are lower when the probability of default is higher. This misperception induces firms to rely too little on debt compared with other sources of funding for which the risk of default is lower. We believe this effect is particularly relevant in markets in which the firms purchasing assets at fire-sale prices are the same firms running the risk of default.

1. Related Literature

The classical literature on the firm's investment decision excludes external finance constraints and bankruptcy costs and uses adjustment costs to explain the reliance of investment on Tobin's q (see Eberly, Rebelo, and Vincent 2008 for a contemporary example). The new wave literature on investment, exemplified by Sundaresan, Wang, and Yang (2014) and Bolton, Chen, and Wang (2013), incorporates financing frictions of various types, such as a cost of external funds, liquidity constraints, and costs of liquidating the firm's assets. Hackbarth and Mauer (1979) then also allow for multiple debt issues with possibly different seniority. These papers study the investment and financing decisions of an individual firm in partial equilibrium.

A few papers, like our work, consider dynamic general equilibrium models with several heterogeneous firms making optimal investment and financing decisions. Gomes and Schmid (2010) and Miao and Wang (2010) study an environment fairly close to ours: they also examine a representative agent economy in which firms' investment can be financed with debt or equity, subject to a similar structure of costs. The liquidation cost, in the event of default, is exogenous in their setup, whereas it is endogenously determined in ours by the equilibrium price of liquidated assets. Also, they focus on the numerical analysis of an equilibrium for a specification of the model aimed to match the persistence and volatility of output growth, as well as credit spreads, whereas we provide a qualitative characterization of equilibria and their welfare properties. The links between firms' credit risk and their leverage and investment decisions across the business cycle are examined by Kuehn and Schmid (2014) in a partial equilibrium model with similar costs of financing.

The macroeconomic literature has emphasized the role of external finance constraints in the business cycle. The financial accelerator model (Bernanke and Gertler 1989; Bernanke, Gilchrist, and Gertler 1999; Kiyotaki and Moore 1997) shows that shocks to firm equity or the value of collateral can restrict borrowing and amplify business-cycle fluctuations. Our focus is rather different: we

consider an environment in which financial frictions take the form of private costs of debt or equity financing rather than borrowing constraints. We also emphasize the factors that determine the firm's choice of capital structure and the implications of these factors for welfare and regulatory interventions.

Eisfeldt and Rampini (2006) have shown that capital reallocation is procyclical, whereas default is countercyclical. This might suggest that reallocation of capital associated with fire sales might be a relatively small part of capital reallocation as a whole. Because Eisfeldt and Rampini's (2006) data is not broken down by the amount of reallocation that results from fire sales, we are un of the size of that component. This is a question that requires further research.⁵

Pecuniary externalities play a key role in our welfare analysis. It has been well known since the mid-1980s that pecuniary externalities have an impact on welfare in the presence of market incompleteness, information asymmetries, or other frictions (Arnott and Stiglitz 1986; Greenwald and Stiglitz 1986; Geanakoplos and Polemarchakis 1986). It is interesting to contrast our constrained inefficiency result to the ones obtained by Lorenzoni (2008) (see also Bianchi 2011; Korinek 2012; Gersbach and Rochet 2012) in a financial accelerator model of the kind discussed in the previous paragraph, in which firms' borrowing is constrained by the future value of their assets. These authors show that equilibria may display excessive borrowing, because a reduction in borrowing and investment allows the reduction of misallocation costs of selling some of the firms' assets in order to absorb negative shocks. In contrast, we show the inefficiency of the firms' capital structure decisions in equilibrium in an environment in which firms are not constrained by the level of their collateral, but face some (endogenous) costs of using alternative sources of funding. We find that an increase in the use of debt relative to equity allows firms to lower their cost of funds, because the liquidation of the assets of bankrupt firms at fire-sale prices constitutes not only a cost for a firm when bankrupt but also a benefit for the same firm when solvent, a concept which firms fail to properly internalize.

The interaction between illiquidity and incompleteness of asset markets is also studied in the literature on banking and financial crises. For models of fire sales and their impact on bank portfolios, see Allen and Gale (2004a, 2004b). Wagner (2011) studies the impact of fire sales on agents' portfolio choices: the possibility of forced liquidation by leveraged investors leads them to choose heterogeneous portfolios, thus sacrificing some of the benefits of diversification.

The debt renegotiation process in our model was previously used by Gale and Gottardi (2011) in a static model in which, by assumption, all investment was 100% debt financed.

⁵ The data that Eisfeldt and Rampini (2006) use to measure capital reallocation is deflated using the CPI. Since the price of capital may vary over the cycle and would be expected to be lower in distress sales than in non-distressed sales, the figures are likely to understate capital reallocation resulting from fire sales.

2. The Economy

We consider an infinite-horizon production economy. Time is described by a countable sequence of dates, $t=0, 1, \dots$. At each date there are two goods, a perishable consumption good and a durable capital good.

2.1 Consumers

There is a unit mass of identical, infinitely lived consumers. The consumption stream of the representative consumer is denoted by $\mathbf{c}=(c_0, c_1, \dots) \geq \mathbf{0}$, where c_t is the amount of the consumption good consumed at date t . For any $\mathbf{c} \geq \mathbf{0}$, the representative consumer's utility is denoted by $U(\mathbf{c})$ and given by

$$U(\mathbf{c}) = \sum_{t=0}^{\infty} \delta^t u(c_t), \quad (1)$$

where $0 < \delta < 1$ and $u: \mathbf{R}_+ \rightarrow \mathbf{R}$ has the usual properties: it is C^2 and such that $u'(c) > 0$ and $u''(c) < 0$ for any $c \geq 0$.

2.2 Production

There are two production sectors in the economy. In one, capital is produced using the consumption good as an input. In the other, the consumption good is produced using the capital good as an input.

2.2.1 Capital goods sector. There is a unit mass of firms operating the technology for producing capital. If $I_t \geq 0$ is the amount of the consumption good used as an input at date t , the output is $\varphi(I_t) \geq 0$ units of capital at the end of the period, where $\varphi(\cdot)$ is a C^2 function satisfying $\varphi'(I_t) > 0$ and $\varphi''(I_t) < 0$, for any $I_t \geq 0$, as well as the Inada conditions, $\lim_{I \rightarrow 0} \varphi'(I) = \infty$ and $\lim_{I \rightarrow \infty} \varphi'(I) = 0$.

2.2.2 Consumption goods sector. The technology for producing the consumption good uses capital as an input and exhibits constant returns to scale. Production in this sector is undertaken by a continuum of firms subject to independent stochastic depreciation rates. Each unit of capital good used as an input by firm i at an arbitrary date t produces (instantaneously) $A > 0$ units of output and becomes θ_{it} units after production takes place. The random variables θ_{it} are assumed to be i.i.d. across firms, as well as over time, with mean $\bar{\theta}$, support $\in [0, 1]$, and a continuous p.d.f. $f(\theta)$. We denote the c.d.f. by $F(\theta)$ and the only other condition we impose on the distribution of θ is that the hazard rate $\frac{f(\theta)}{1-F(\theta)}$ is increasing.

2.3 Feasible allocations

At date 0, there is an initial stock of capital goods $\bar{k}_0 > 0$. To characterize the allocations attainable in this economy, the heterogeneity among firms and the

idiosyncratic depreciation shocks can be ignored, because production can be diversified across the large number of firms. By the law of large numbers convention, there is no aggregate uncertainty and the aggregate depreciation rate is constant, with a fraction $\bar{\theta}$ of the capital stock remaining each period after depreciation. Thus, a total amount of $k_t \geq 0$ units of capital goods at date t produces Ak_t units of consumption and leaves, after depreciation, $\bar{\theta}k_t$ units of capital goods to be used next period.

A (symmetric) allocation is thus given by a sequence $\{c_t, k_t, I_t\}_{t=0}^{\infty}$ that specifies the consumption c_t , capital k_t , and investment I_t at each date t . The allocation $\{c_t, k_t, I_t\}_{t=0}^{\infty}$ is feasible if, for every date $t=0, 1, \dots$, it satisfies nonnegativity,

$$(c_t, k_t, I_t) \geq \mathbf{0}, \quad (2)$$

attainability for the consumption good,

$$c_t + I_t \leq Ak_t, \quad (3)$$

and the law of motion for capital,

$$k_{t+1} = \bar{\theta}k_t + \varphi(I_t), \quad (4)$$

together with the initial condition $k_0 = \bar{k}_0$.

It follows from the assumptions regarding the technology for producing the capital good that there exists a unique level of the capital stock, $0 < \hat{k} < \infty$, satisfying the condition

$$\varphi(A\hat{k}) = (1 - \bar{\theta})\hat{k}.$$

When the capital stock at the beginning of a period is equal to \hat{k} , if all the current output of the consumption good is used for investment, the amount of capital available at the end of the period remains constant, equal to \hat{k} . It is then straightforward to show that \hat{k} constitutes an upper bound on the permanently feasible levels of the stock of capital.

Proposition 1. At any feasible allocation $\{c_t, k_t, I_t\}_{t=0}^{\infty}$, we have $\limsup_{t \rightarrow \infty} k_t \leq \hat{k}$.

As a corollary, $A\hat{k}$ is an upper bound on the levels of consumption and investment that can be maintained indefinitely:

$$\limsup_{t \rightarrow \infty} c_t \leq A\hat{k}, \quad \limsup_{t \rightarrow \infty} I_t \leq A\hat{k}.$$

2.4 Efficient allocations

A first-best, socially optimal allocation maximizes the utility of the representative consumer within the set of feasible allocations. More precisely, it is a sequence $\{c_t, k_t, I_t\}_{t=0}^{\infty}$ that solves the problem of maximizing the

representative consumer's utility (1) subject to the feasibility constraints (2), (3), and (4).

To characterize the properties of the first-best, consider the necessary and sufficient conditions for an interior solution $(c_t^{FB}, k_t^{FB}, I_t^{FB}) \gg 0$, $t=0, 1, \dots$ of this problem. For some nonnegative multipliers $\{(\lambda_t, \mu_t)\}_{t=0}^\infty$, the allocation $\{(c_t^{FB}, k_t^{FB}, I_t^{FB})\}_{t=0}^\infty$ must satisfy the conditions

$$\delta^t u'(c_t^{FB}) = \lambda_t,$$

$$\lambda_{t+1} A + \mu_{t+1} \bar{\theta} = \mu_t,$$

and

$$\mu_t \varphi'(I_t^{FB}) = \lambda_t,$$

for every t , together with the feasibility conditions (2)-(4) and the initial condition $k_0 = \bar{k}_0$. The boundedness property established above implies that the transversality condition

$$\lim_{t \rightarrow \infty} \sum_{s=t}^{\infty} \delta^s u(c_s) = 0$$

is automatically satisfied.

Much of our analysis focuses on steady states, that is, on allocations such that

$$(c_t, k_t, I_t) = (c, k, I)$$

for all t . It is interesting to see what the above first-order conditions imply for an optimal steady state:

Proposition 2. At an optimal steady state, the capital stock is given by

$$k^{FB} = \frac{\varphi(I^{FB})}{1 - \bar{\theta}}, \quad (5)$$

where I^* is determined by

$$\frac{\delta A}{1 - \delta \bar{\theta}} = \frac{1}{\varphi'(I^{FB})}. \quad (6)$$

Condition (6) has a natural interpretation in terms of marginal costs and benefits. The marginal revenue of a unit of capital at the end of period 0 is

$$\frac{\delta A}{1 - \delta \bar{\theta}} = \delta A + \delta^2 \bar{\theta} A + \dots + \delta^t \bar{\theta}^{t-1} A + \dots,$$

because it produces $\bar{\theta}^{t-1} A$ units of the consumption good at each date $t > 0$ and the present value of that consumption is $\delta^t \bar{\theta}^{t-1} A$. The marginal cost of a unit of capital is $\frac{1}{\varphi'(I^{FB})}$ units of consumption at date 0. So the optimality condition (6) requires the equality of marginal cost and marginal revenue.

3. An Incomplete Markets Economy

In this section we specify the structure of markets available in this economy and study the decision problems of individual firms and consumers.

3.1 Firms and markets

In the capital goods sector, because production is instantaneous and no capital is used, firms simply maximize current profits in each period.

In the consumption sector, firms use capital, are infinitely lived, and choose their investment level and financing strategy each period in the available markets. Firms are *ex ante* identical but are subject to idiosyncratic depreciation shocks each period. Their *ex post* heterogeneity cannot be ignored when we study their investment and financing decisions.

In a frictionless environment, in which firms have access to a complete set of contingent markets to borrow against their future income stream and hedge the idiosyncratic depreciation shocks, the first-best allocation can be decentralized, in the usual way, as a perfectly competitive equilibrium. In what follows, we consider instead an environment with financial frictions, where there are no markets for contingent claims, firms are financed exclusively with debt and equity, and their output is sold in spot markets. In this environment, as we will see, the first-best is typically not attainable.

In the presence of uncertainty regarding the amount and value of a firm's capital in the subsequent period, debt financing gives rise to the risk of bankruptcy. This may be perceived by the firm as costly because, in the event of default, the firm is required to liquidate its assets by selling them to firms that remain solvent. These firms, though solvent, may be finance constrained. When this happens, there will be a fire sale, in which assets are sold for less than their full economic value.

Equity financing, by contrast, entails no bankruptcy risk. The disadvantage of equity is that firms must pay a (distortionary) tax on equity's returns. We assume for simplicity that the revenue of the tax on equity is used to make an equal lump sum transfer to all consumers.

Both sources of funding, debt and equity, entail some private costs for firms in the consumption goods sector. Firms choose their optimal capital structure in each period, that is, the composition of outstanding debt and equity, by trading off the relative costs and benefits.

Given the CRTS property of the technology, the size of individual firms and the mass of firms active in the consumption goods sector are indeterminate. Moreover, because there will be bankruptcy of some of the existing firms and we allow for entry of new firms, the mass of active firms may change over time. To simplify the description of equilibrium, we will focus our attention on the case in which a combination of entry and exit maintains the mass of firms equal to unity and firms adjust their size so that each of them has the same amount of capital. Given the inherent indeterminacy of equilibrium in the consumption

goods sector, this assumption entails no essential loss of generality and allows us to describe the evolution of the economy in terms of a representative firm with capital stock k_t .

At the initial date $t=0$, we assume that all capital is owned by firms in the consumption goods sector and that each of these firms has been previously financed entirely by equity. Each consumer has an equal shareholding in each firm in the two sectors.

In what follows we shall focus our attention on the case in which all firms' debt has a maturity of one period, so that the entire debt is due for repayment one period after it is issued. Alternatively, we could have assumed a maturity of n periods. In that case, the repayment due each period would be smaller. However, debt with longer maturity also creates a moral hazard problem for creditors, because creditors have little power over a firm as long as it pays the required interest and principal in any period. Hence, equity holders could enrich themselves at the expense of bond holders, paying themselves large dividends by selling off capital until the firm is worthless. To address this problem long-term bond contracts typically contain multiple covenants controlling the behavior of the firm. For instance, covenants might restrict the firm's ability to issue new debt, require the firm to maintain an adequate ratio of earnings to interest payments, the so-called interest coverage ratio, or to maintain the value of its assets in relation to the value of debt. If any of those covenants is violated, the firm is technically in default and the repayment of the entire debt is due immediately, forcing a renegotiation of the debt, similarly to the case of one-period bonds. In the Online Appendix, we show how the model can be extended to the special case of perpetual bonds, in which covenants give rise to default precisely as it occurs with one-period bonds.

To analyze the firms' decision formally we must first describe in more detail the structure of markets and the timing of the debt renegotiation process, leading possibly to default and liquidation.

3.2 Renegotiation and default

Each date t is divided into three subperiods, labeled A , B , and C .

- A. In the first subperiod (A), the production of the consumption good occurs and the depreciation shock of each firm i , θ_{it} , is realized. Also, the debt liabilities of each firm are due. The firm has three options: it can repay the debt; renegotiate ("roll over") the debt; or it can default and declare bankruptcy. Renegotiation is modeled by a game described in the next section. If renegotiation succeeds, the firm remains solvent and may then distribute its earnings to equity holders or retain them to finance new purchases of capital.
- B. In the intermediate subperiod (B), the market in which bankrupt firms can sell their assets (capital goods) opens. A finance constraint applies, so that only agents with ready cash, either solvent firms who retained

earnings in subperiod *A* or consumers who received dividends in subperiod *A*, can purchase the assets on sale. Let q_t denote the market price of the liquidated capital.

- C. In the final subperiod (*C*), the production of capital goods occurs. The profits of the firms who operate in this sector are distributed to the consumers who own them. In addition, debt holders of defaulting firms receive the proceeds of the liquidation sales in subperiod *B*. The taxes on equity's returns are due and the lump sum transfers to consumers are also made in this subperiod. All remaining markets open. Consumption and capital goods are traded on spot markets, and firms issue debt and equity to finance the purchase of new capital goods. Consumers buy and sell these securities to fund future consumption and rebalance their portfolios. Equilibrium requires that $q_t \leq v_t$, where v_t is the price of capital in subperiod *C*; if $q_t > v_t$ no firm buys capital at the price q_t and capital goods are in excess supply in subperiod *B*, contradicting the equilibrium conditions.

Agents face no finance constraint in the markets in subperiod *C*. We can interpret the fact that this constraint only applies to the markets for liquidated assets in subperiod *B* as portraying the haste with which the firms' assets need to be sold after a default. It can also be taken as an institutional feature of the bankruptcy process that does not apply to other markets.

Bankruptcy procedures are the source of numerous possible frictions (see Bebhuk 1988; Aghion, Hart, and Moore 1992; Shleifer and Vishny 1992). In the present model, we focus on one potential source of market failure, the so-called finance constraint, which requires buyers to pay for their purchases of assets with the funds (cash) available to them, not with the issue of IOUs.⁶ Hence, the potential buyer may not be able to raise enough finance to purchase the assets at their full economic value. This is the cost of bankruptcy as perceived by firms in the environment considered and is endogenously determined in equilibrium.⁷

We believe that our model of capital markets, with a clear distinction between liquidation markets, represented by subperiod *B* in which only cash is accepted, and normal markets, represented by subperiod *C* in which firms have complete access to external finance and there is no finance constraint, is a reasonable approximation of reality. It is generally accepted that capital markets are not

⁶ The finance constraint takes the form of a liquidity constraint similar to the familiar cash-in-advance constraint used in macroeconomic and monetary models. We prefer the term finance constraint, first, because there is no money in the model and, second, because we interpret the constraint as merely ruling out the possibility of borrowing to fund the purchase of asset trades due to the urgency of these transactions, rather than requiring "cash on the barrelhead."

⁷ In the dynamic environment considered, at any t both the resale price q_t and the full value v_t are endogenous. As further discussed in Section 5.2, we could allow for an additional, deadweight cost of bankruptcy, with no substantial change in the results.

perfect and it is costly and time consuming for firms to obtain external finance. A firm with sufficient time available may find it feasible to raise finance for new capital goods by issuing debt and/or equity. In contrast, when a distressed firm sells assets in a fire sale, firms in the same industry do not have the time to obtain external finance and have to rely on retained earnings to purchase these assets.⁸ The distinction between markets for liquidated assets, in which assets have to be sold in a hurry, and normal asset markets is obviously a matter of degree. Here, we have made the distinction sharper than it is in reality by assuming the market for liquidated capital goods is “cash only,” whereas firms in the other market have “free” access to external finance. This makes the model tractable, without distorting reality too much, but the distinction could be weakened without substantial qualitative change.

3.2.1 Subperiod A: The renegotiation game. Consider a firm with k_t units of capital and an outstanding debt with face value $d_t k_t$ ⁹ at the beginning of period t . The firm produces Ak_t units of the consumption good, learns the realization of its depreciation shock θ_t and must then choose whether to repay the debt or try to renegotiate it. The renegotiation process that occurs in subperiod A between the firm and the creditors who purchased the firm’s bonds at $t - 1$ is represented by a two-stage game.

- S1. The firm makes a “take-it-or-leave-it” offer to the bond holders to rollover the debt, replacing each unit of the maturing debt with face value d_t with a combination of equity and debt maturing the following period. The new face value of the debt, d_{t+1} , determines the firm’s capital structure because equity is just a claim to the residual value.
- S2. The creditors simultaneously accept or reject the firm’s offer.

Two conditions must be satisfied for renegotiation to succeed. First, a majority of the creditors must accept the offer. Second, the rest of the creditors must be paid off in full. If either condition is not satisfied, the renegotiation fails and the firm is declared bankrupt. In that event, all the assets of the firm are frozen, nothing is distributed until the capital stock has been liquidated (sold in the market). After liquidation, the sale price of the liquidated assets is distributed to the bond holders in subperiod C. Obviously, there is nothing left for the shareholders in this case. Hence, default is always involuntary: a firm acting so as to maximize its market value will always repay or roll over the debt unless it is unable to do so.

Next, we show that there is an equilibrium of this renegotiation game in which renegotiation succeeds if and only if

$$d_t k_t \leq (A + q_t \theta_t) k_t, \quad (7)$$

⁸ A model of this process is found in Shleifer and Vishny (1992).

⁹ Here, and in what follows, it is convenient to denote the face value of the debt issued per unit of capital acquired by d_t .

that is, if the value of the firm's equity is negative when its capital is evaluated at its liquidation price q_t . Note that the condition is independent of k_t .

Consider, with no loss of generality, the case of a firm with one unit of capital, that is, $k_t = 1$, and take an individual creditor holding debt with face value d_t . If he rejects the offer and demands to be repaid immediately, he receives d_t in subperiod A. With this payment, because $q_t \leq v_t$, we can assume without loss of generality that he purchases $\frac{d_t}{q_t}$ units of capital in subperiod B. Similarly, if the firm manages to roll over its debt, it can retain its cashflow A and purchase $\frac{A}{q_t}$ units of capital in subperiod B. Then it will have $\frac{A}{q_t} + \theta_t$ units of capital at the start of subperiod C. Therefore, the most that the firm can offer the creditor is a claim to an amount of capital $\frac{A}{q_t} + \theta_t$ at the beginning of subperiod C, with market value $v_t \left(\frac{A}{q_t} + \theta_t \right)$. The firm's offer will be accepted only if the creditor rejecting the offer obtains no more capital than by accepting. Hence, the firm is only able to make an offer that is accepted if

$$\frac{d_t}{q_t} \leq \frac{A}{q_t} + \theta_t,$$

which is equivalent to (7).

If (7) is satisfied, there exists a subgame perfect equilibrium of the renegotiation game in which the firm makes an acceptable offer worth d_t/q_t units of capital at the end of the period to the creditors and all of them accept. To see this, note first that the shareholders receive a nonnegative payoff from rolling over the debt, whereas they get nothing in the event of default. Second, the creditors will accept the offer of d_t/q_t because they cannot get a higher payoff by deviating and rejecting it, and they will not accept a lower offer. Thus, we have the following simple result.

Proposition 3. There exists a subgame perfect equilibrium of the renegotiation game, in which the debt is renegotiated if and only if (7) is satisfied.

Proposition 3 leaves open the possibility that renegotiation may fail even if (7) is satisfied. Indeed, it is the case that if every other creditor rejects the offer, it is optimal for a creditor to reject the offer because a single vote has no effect. In the sequel, we ignore this trivial coordination failure among lenders and assume that renegotiation succeeds whenever (7) is satisfied, to explore other, less trivial, sources of inefficiency.

3.2.2 Subperiod B: Liquidation. Let z_t denote the break even value of θ_t , implicitly defined by the following equation

$$d_t \equiv A + q_t z_t. \quad (8)$$

Thus, renegotiation fails and a firm is bankrupt if and only if $\theta_t < z_t$. When all firms active at the beginning of date t have the same size (k_t), the supply of

capital to be liquidated by bankrupt firms in subperiod B is

$$\int_0^{z_t} \theta_t k_t f(\theta_t) d\theta_t.$$

If $q_t < v_t$, a manager operating a solvent firm in the interest of its shareholders will roll over the entire amount of its debt in subperiod A and retain all its earnings to have them available to purchase capital at fire sale prices in subperiod B . This choice maximizes the firm's market value and shareholders can always sell their shares to finance consumption. On the other hand, if $q_t = v_t$ solvent firms are indifferent between retaining their earnings or distributing them as dividends. The maximal amount of resources available to purchase capital in subperiod B is then given by the total revenue of solvent firms (with $\theta_t \geq z_t$)

$$A \int_{z_t}^1 k_t f(\theta_t) d\theta_t = A(1 - F(z_t))k_t.$$

Hence, market clearing in the liquidation market requires

$$q_t \int_0^{z_t} \theta_t k_t f(\theta_t) d\theta_t \leq A(1 - F(z_t))k_t, \quad (9)$$

with (9) holding with equality if $q_t < v_t$, in which case all the available resources of solvent firms must be offered in exchange for liquidated capital.

3.2.3 Subperiod C: Settlement, investment, and trades. The decision of the firms operating in the capital goods sector, in subperiod C , is simple. At any date t , the representative firm chooses $I_t \geq 0$ to maximize current profits, $v_t \varphi(I_t) - I_t$. Because of the concavity of the production function, a necessary and sufficient condition for the investment level I_t to be optimal is

$$v_t \varphi'(I_t) \leq 1, \quad (10)$$

with strict equality if $I_t > 0$. The profits from the capital sector, $\pi_t = \sup_{I_t \geq 0} \{v_t \varphi(I_t) - I_t\}$, are then paid to consumers in the same subperiod.

In the consumption goods sector, the firms' decision is more complicated because the production of consumption goods requires capital, which generates returns that repay the investment over time. So the firm needs funds, issuing debt and equity to finance the purchase of capital.

As we explained above, the number and size of firms in this sector are indeterminate because of constant returns to scale. We consider a symmetric equilibrium in which, at any date, a unit mass of firms are active and all of them have the same size, given by k_t units of capital,¹⁰ at the end of date t . The

¹⁰ Because a fraction of firms default each period, the surviving firms who acquire their capital may grow in size in sub-period B but are then indifferent between buying or selling capital at v_t in sub-period C . Hence, we can always consider a situation in which the mass of active firms remains unchanged over time, whereas their size varies with k_t .

representative firm chooses its capital structure to maximize its market value, that is, the value of the outstanding debt and the equity claims on the firm. This capital structure is summarized by the breakeven point¹¹ z_{t+1} . Whenever the firm's depreciation shock next period is $\theta_{t+1} < z_{t+1}$, the firm defaults and its value (again per unit of capital held at the end of date t) is equal to the value of the firm's liquidated assets, $A + q_{t+1}\theta_{t+1}$. If $\theta_{t+1} > z_{t+1}$, the firm is solvent and can use its earnings A to purchase capital at the price q_{t+1} . Then the pretax value of the firm is $v_{t+1} \left(\frac{A}{q_{t+1}} + \theta_{t+1} \right)$.

With regard to the corporate tax, the accounting treatment of depreciation in the presence of fire sales poses some problems in calculating corporate income. For simplicity, we assume that the tax base is the value of the firm's equity at the beginning of subperiod C , whenever it is non negative. The tax rate is then denoted by $\tau > 0$. This tax has the same qualitative properties as the corporate income tax, in the sense that it is a tax on capital goods and gives preferred treatment to interest on debt.¹²

To calculate the value of equity, we need to subtract from the value of capital owned by the firm, $v_{t+1} \left(\frac{A}{q_{t+1}} + \theta_{t+1} \right)$, and the value of the (renegotiated) debt, $v_{t+1} \left(\frac{d_{t+1}}{q_{t+1}} \right)$. The tax base is

$$v_{t+1} \left(\frac{A}{q_{t+1}} + \theta_{t+1} \right) - v_{t+1} \left(\frac{d_{t+1}}{q_{t+1}} \right) \quad (11)$$

and the tax payment due at date $t + 1$, in subperiod C , is

$$\tau \max \left\{ v_{t+1} \left(\frac{A}{q_{t+1}} + \theta_{t+1} \right) - v_{t+1} \left(\frac{d_{t+1}}{q_{t+1}} \right), 0 \right\} = \tau \max \left\{ \frac{v_{t+1}}{q_{t+1}} (A + q_{t+1}\theta_{t+1} - d_{t+1}), 0 \right\}.$$

Because there is no aggregate uncertainty, and there is a continuum of firms offering debt and equity subject to idiosyncratic shocks, diversified debt and equity are risk-free and must bear the same rate of return. Denoting by r_t the risk-free interest rate between dates t and $t + 1$, the value of the firm at t is given by the expected value of the firm at date $t + 1$

$$\int_0^{z_{t+1}} (A + q_{t+1}\theta_{t+1}) dF + \int_{z_{t+1}}^1 \left[v_{t+1} \left(\frac{A}{q_{t+1}} + \theta_{t+1} \right) - \tau \frac{v_{t+1}}{q_{t+1}} (A + q_{t+1}\theta_{t+1} - d_{t+1}) \right] dF, \quad (12)$$

¹¹ The level of z determines the face value of the debt as in (8).

¹² In the Online Appendix we show formally the equivalence between a proportional tax on corporate earnings and a proportional tax on the value of equity in a slightly simpler specification of the environment, where depreciation is nonstochastic.

divided by $1+r_t$. Hence, the firm's problem consists in the choice of its capital structure, as summarized by z_{t+1} , so as to maximize the following objective function

$$\frac{1}{1+r_t} \left\{ \int_0^{z_{t+1}} (A+q_{t+1}\theta_{t+1}) dF + \int_{z_{t+1}}^1 \left[v_{t+1} \left(\frac{A}{q_{t+1}} + \theta_{t+1} \right) - \tau v_{t+1} (\theta_{t+1} - z_{t+1}) \right] dF \right\} \quad (13)$$

in which we used (8) to substitute for d_{t+1} in (12). The solution of the firm's problem has a fairly simple characterization:

Proposition 4. When¹³ $v_{t+1} > q_{t+1}$ there is a unique solution z_t for the firm's optimal capital structure, given by $z_{t+1}=0$ when $\left(1 - \frac{q_{t+1}}{v_{t+1}}\right) Af(0) \geq \tau$ and by $0 < z_t < 1$ satisfying

$$\left(\frac{1}{q_{t+1}} - \frac{1}{v_{t+1}} \right) (A + q_{t+1}z_{t+1}) \frac{f(z_{t+1})}{1 - F(z_{t+1})} = \tau$$

when $\left(1 - \frac{q_{t+1}}{v_{t+1}}\right) Af(0) < \tau$.

The value of the firm (per unit of capital) at a solution of (13) is then equal to the market value of capital, v_t .

The representative consumer has an income flow generated by his initial ownership of shares of firms in the two sectors, equal to the date 0 value of firms with capital k_0 in the consumption goods sector plus the payment each period of the profits π_t of firms in the capital good sector. In addition, he receives lump sum transfers T_t from the government at every date. Because he faces no income risk and can fully diversify the idiosyncratic income risk of equity and corporate debt, the consumer effectively trades a riskless asset each period. His choice problem reduces to the maximization of the discounted stream of utility subject to the lifetime budget constraint:

$$\begin{aligned} \max \quad & \sum_{t=0}^{\infty} \delta^t u(c_t) \\ \text{s.t.} \quad & c_0 + \sum_{t=1}^{\infty} p_t c_t = Ak_0 + v_0 \bar{\theta} k_0 + \pi_0 + \sum_{t=1}^{\infty} p_t (T_t + \pi_t), \end{aligned} \quad (14)$$

where $p_t = \prod_{s=0}^{t-1} \frac{1}{1+r_s}$ is the discount rate between date 0 and date t , given the access to risk free borrowing and lending each period at the rate r_t .¹⁴

¹³ When $v_{t+1} = q_{t+1}$, the solution is clearly full debt financing, $z_{t+1} = 1$.

¹⁴ The (average) value of firms owning the initial endowment of capital k_0 equals the value of the output Ak_0 produced with this capital in sub-period A , plus the value of the capital left after depreciation in sub-period C , $\bar{\theta} k_0 v_0$. Because they are, as we said, financed entirely with equity, this coincides with their equity value. Also, while producers of capital good operate and hence distribute profits in every period $t \geq 0$, the first equity issue is at the end of date 0, and hence the first tax revenue on equity earnings is at date $t = 1$.

The market-clearing condition for the consumption good is

$$c_t + I_t = Ak_t, \quad \text{for all } t \geq 0. \quad (15)$$

The markets for debt and equity clear, at any t , if the amount of households' savings is equal to the value of debt and equity issued by firms in that period. We show in the Appendix that the market-clearing condition for the securities markets is automatically satisfied if the market-clearing condition for the consumption goods market (15) is satisfied. This is just an application of Walras' law.

Finally, the market for capital clears if

$$k_{t+1} = \bar{\theta}k_t + \varphi(I_t). \quad (16)$$

4. Equilibrium

We are now ready to state the equations defining a competitive equilibrium in the environment described.

Definition 1. A competitive equilibrium is a sequence of values $\{(c_t^*, k_{t+1}^*, z_{t+1}^*, I_t^*, q_t^*, v_t^*, r_t^*)\}_{t=0}^{\infty}$ satisfying the following conditions.

1. PROFIT MAXIMIZATION IN THE CAPITAL GOODS SECTOR. For every date $t \geq 0$, I_t^* solves (10).

2. OPTIMAL CAPITAL STRUCTURE. For every date $t \geq 0$, the capital structure z_{t+1}^* of the firms in the consumption goods sector satisfies:

$$\left(\frac{1}{q_{t+1}^*} - \frac{1}{v_{t+1}^*} \right) (A + q_{t+1}^* z_{t+1}^*) \frac{f(z_{t+1}^*)}{1 - F(z_{t+1}^*)} = \tau,$$

and the value of firms in this sector satisfies the law of motion

$$(1 + r_t^*) v_t^* = \left\{ \int_0^{z_{t+1}^*} (A + q_{t+1}^* \theta_{t+1}) dF + \int_{z_{t+1}^*}^1 \left(v_{t+1}^* \left(\frac{A}{q_{t+1}^*} + \theta_{t+1} \right) - \tau v_{t+1}^* (\theta_{t+1} - z_{t+1}^*) \right) dF \right\}.$$

3. OPTIMAL CONSUMPTION. The sequence $\{c_t^*\}_{t=0}^{\infty}$ satisfies the following first-order conditions

$$\frac{\delta u'(c_{t+1}^*)}{u'(c_t^*)} = \frac{1}{1 + r_t^*},$$

for every date $t \geq 0$, together with the budget constraint

$$c_0^* + \sum_{t=1}^{\infty} \left(\prod_{s=0}^{t-1} \frac{1}{1 + r_s^*} \right) c_t^* = Ak_0 + v_0^* \bar{\theta} k_0 + v_0^* \varphi(I_0^*) - I_0^* + \sum_{t=1}^{\infty} \left(\prod_{s=0}^{t-1} \frac{1}{1 + r_s^*} \right) \left(\tau k_t^* v_t^* \int_{z_t^*}^1 (\theta_t - z_t^*) f(\theta_t) d\theta_t + v_t^* \varphi(I_t^*) - I_t^* \right).$$

4. LIQUIDATION MARKET CLEARING. For every date $t > 0$, $q_t^* \leq v_t^*$ and (9) holds.
5. CONSUMPTION GOODS MARKET CLEARING. For every date $t \geq 0$, (15) holds.
6. CAPITAL MARKET CLEARING. For every date $t \geq 0$, the sequence $\{k_t^*\}$ satisfies (16) and $k_0^* = \bar{k}_0$.

Condition 1 requires firms in the capital goods sector to maximize profits at every date, taking the price of capital goods v_t^* as given. Condition 2 requires firms in the consumption goods sector to choose their capital structures optimally. The law of motion for the value of the firm is simply the Bellman equation associated with the maximization problem in Equation (13). Condition 3 requires that the consumption path solves the consumers' maximization problem (14). Conditions 4–6 are the market-clearing conditions for the liquidated capital goods market in subperiod B and for consumption goods and capital goods market in subperiod C .

The equilibrium market prices of equity v_t^{e*} and debt v_t^{b*} (per unit of capital) at any date t are readily obtained from the other equilibrium variables.¹⁵ Note that the debt equity ratio, given by¹⁶

$$\frac{v_t^{b*}}{v_t^{e*}} = \frac{\int_0^{z_{t+1}^*} (A + q_{t+1}^* \theta) dF + \int_z^1 v_{t+1}^* \left(\frac{A}{q_{t+1}^*} + z_{t+1}^* \right) dF}{\int_{z_{t+1}^*}^1 v_{t+1}^* (\theta - z_{t+1}^*) (1 - \tau) dF}, \quad (17)$$

is always increasing in z_{t+1}^* . The denominator of (17) is in fact clearly decreasing in z_{t+1}^* . Because $v_t^{b*} + v_t^{e*} = v_t^*$ and z_{t+1}^* maximizes the firms' market value v_t^* the numerator must then increase with z_{t+1}^* .

Putting together the market-clearing condition (9) for liquidated capital in subperiod B with the optimality conditions for the firms in the consumption goods sector (Proposition 4), we see that in equilibrium we must have an interior optimum for the firms' capital structure: $z_t \in (0, 1)$ and $q_t < v_t$.¹⁷ Thus, default occurs with probability strictly between zero and one:

$$0 < F(z_t) < 1,$$

and results in a fire sale. Intuitively, if there were no fire sale ($q_t = v_t$) firms would choose 100% debt financing, but this implies default with probability one, which is inconsistent with market clearing. Similarly, 100% equity financing for all firms implies that there is no default and no fire sale, so each firm would rather use 100% debt financing. The only remaining alternative is that firms use a mixture of debt and equity and face the possibility of fire sales.

¹⁵ As explained above, the returns on diversified equity and debt are deterministic. Thus, v_t^{e*} and v_t^{b*} must be such that the one-period expected returns on debt and equity are equal to the risk free-rate.

¹⁶ The term on the denominator, is obtained from the expression of the pretax value of the equity of the firm, when solvent, obtained in (11). This is then subtracted from the overall value of the firm, in (13), to obtain the value of debt.

¹⁷ Condition 2 above is in fact stated for this case.

We also see from the previous analysis that uncertainty only affects the returns and default decisions of individual firms. All other equilibrium variables, aggregate consumption, investment, and market prices are deterministic.

4.1 Steady-state equilibria

A steady state is a competitive equilibrium $\{(c_t^*, k_t^*, z_t^*, I_t^*, q_t^*, v_t^*, r_t^*)\}_{t=0}^{\infty}$ in which for all $t \geq 0$

$$(c_t^*, k_t^*, z_t^*, I_t^*, q_t^*, v_t^*, r_t^*) = (c^*, k^*, z^*, I^*, q^*, v^*, r^*).$$

We show first that a steady state exists and is unique. In addition, the system of conditions defining a steady state can be reduced to a system of two equations.

Proposition 5. Under the maintained assumptions, there exists a unique steady-state equilibrium, obtained as a solution of the following system of equations:

$$q^* = \frac{A(1 - F(z^*))}{\int_0^{z^*} \theta f(\theta) d\theta}, \quad (18)$$

$$v^* = \frac{\delta A}{1 - \delta \bar{\theta} + \tau \delta \int_{z^*}^1 (\theta - z^*) dF} < \frac{\delta A}{1 - \delta \bar{\theta}}, \quad (19)$$

$$\left(\frac{1}{q^*} - \frac{1}{v^*} \right) (A + q^* z^*) \frac{f(z^*)}{1 - F(z^*)} = \tau. \quad (20)$$

We can then also identify some of the comparative statics properties of the steady state.

Proposition 6. (i) An increase in the tax rate τ increases the steady value of z^* (and hence the debt-equity ratio) and reduces that of q^* , but the effect on v^* (and hence I^* and k^*) is ambiguous.

(ii) An increase in the discount factor δ decreases the steady-state value of z^* (and hence the debt-equity ratio) and increases the one of q^* as well of v^* , so that I^* and k^* increase too.

To gain some intuition for these results, consider in particular the case of an increase in the tax rate τ . This increases the cost of equity financing, so that firms shift to higher debt financing, thus decreasing the liquidity available in subperiod B and hence the liquidation value of defaulting firms. Whereas the direct effect of the higher tax rate, by making equity financing costlier, is clearly to decrease v , the fact that the higher tax increases debt financing (z) has an opposite effect on v , increasing it as we see from (19), and, hence, the overall effect on v is ambiguous.

4.2 Transition dynamics

The steady state is often studied because of its simplicity, but non-steady-state paths may have very different properties. For this particular model, however, the steady state is representative of equilibrium paths in general, at least if one is willing to assume that consumers are risk neutral.¹⁸ In that case, we can show that, in any equilibrium, there is a constant equilibrium capital structure that coincides with the steady state capital structure; the same is then true for q , v , and I . Thus, outside the steady state, the only variable that is changing is the capital stock, which converges monotonically to the steady-state value. In this sense, little is lost by focusing on the steady state. The analysis of transition dynamics is included for completeness to the Online Appendix.

5. Welfare Analysis

5.1 The inefficiency of equilibrium

If we compare the conditions for a Pareto-efficient steady state derived in Proposition 2 with the conditions for a steady-state equilibrium derived in Section 4.1, we find that steady-state equilibria are Pareto efficient if $I^* = I^{FB}$, which happens when the equilibrium market value of capital is given by

$$v^* = \frac{\delta}{1 - \delta\theta} A.$$

From the equilibrium conditions, in particular Condition 2, it can be seen immediately that the equality above can hold only if $\tau = 0$. In that case, there is no cost of issuing equity and the firms in the consumption goods sector will choose 100% equity financing. On the other hand, when $\tau > 0$, as we have been assuming, the equilibrium market value of capital v^* is strictly lower than $\frac{\delta}{1 - \delta\theta} A$ and I^* and k^* are strictly less than the corresponding values at the first best steady state. Thus, in a steady-state equilibrium, the financial frictions given by market incompleteness and the costs of default and equity financing as perceived by firms imply that firms invest a lower amount and the equilibrium stock of capital is lower than at the efficient steady state. Hence, even with a representative consumer, competitive equilibria are Pareto inefficient.¹⁹

Short of getting rid of the corporate income tax, a policy of changing the tax rate so as to reduce the tax revenue would also improve welfare. As we saw in

¹⁸ Because there is no aggregate uncertainty, risk aversion is not an issue. The only role played by the curvature of the utility function is to determine the intertemporal marginal rate of substitution (IMRS). By assuming that the utility function is linear, one imposes a constant IMRS. This restricts somewhat the adjustment of endogenous variables along the transition path but is otherwise innocuous.

¹⁹ When the initial capital stock $k_0 = k^{FB}$ the unique Pareto-efficient allocation of the economy is the Pareto-efficient steady state. Because the equilibrium allocation is different, it is clearly Pareto inefficient. For other values of k_0 , the transitional dynamics of the Pareto-efficient allocation needs also to be considered to claim the inefficiency of the equilibrium. This can be shown formally by proceeding along similar lines to the ones of the next section.

the comparative statics exercise,²⁰ such a change in the tax rate will increase the value of the firm (capital goods), causing an increase in investment and consumption. Similarly, policies such as accelerated depreciation, expensing of investments in research and development, or subsidies on investment will also increase welfare.

In our simplified model, all firms are *ex ante* identical. If firms are heterogeneous, however, it might be advantageous to target firms that are vulnerable to fire sales, either because they are riskier or because they have less liquid markets for liquidated capital goods. In that case, a uniform tax rate on corporate income, combined with incentives for particular industries, might be required.

5.2 Constrained inefficiency

It is not surprising that the equilibrium is Pareto inefficient in the presence of financial frictions affecting firms' financing. To assess the scope of policy and regulatory interventions, however, it is more interesting and appropriate to see whether a welfare improvement can be found, taking as given the presence of such frictions (market incompleteness, finance constraints, and distortionary taxation). More precisely, we examine whether regulating the levels of a single endogenous variable, in particular, the capital structure as represented by z , can lead to a welfare improvement, while allowing all other variables to reach their equilibrium levels. If so, we say that competitive equilibria are constrained inefficient.

Suppose the economy is in a steady-state equilibrium and consider an intervention consisting in a permanent²¹ change Δz starting at some fixed but arbitrary date $t+1$. Thus, from this date onward, z is constant and equal to $z^* + \Delta z$. To determine the welfare effects of this intervention, we need to trace the changes in equilibrium prices, investment, and consumption over time and hence the transition to the new steady state. To make this analysis more transparent, we assume as in Section 4.2 that consumers are risk neutral,²² that is, $u(c) = c$.

The induced changes in the equilibrium variables q and v are then obtained by substituting the new value of z into the market-clearing condition in subperiod B , (9),

$$A(1 - F(z^* + \Delta z)) = q_{t+1+i} \int_0^{z^* + \Delta z} \theta dF, \quad (21)$$

²⁰ See in particular the proof of Proposition 6 in the Appendix.

²¹ We focus attention on a permanent intervention, but it is fairly easy to verify that the same welfare result holds in the case of a temporary intervention.

²² See footnote 18 for a discussion of this specification of consumers' preferences.

and the law of motion of v , appearing in condition 2 of the definition of a competitive equilibrium,²³

$$v_{t+i} = \delta \left\{ A + v_{t+1+i} \bar{\theta} - \tau v_{t+1+i} \int_{z^*+\Delta z}^1 (\theta - z^* - \Delta z) dF \right\}, \quad (22)$$

for all $i \geq 0$.²⁴ We see from (21) that the new equilibrium value for q_{t+i} is the same for all i and from (22) we obtain a first-order difference equation in v . The solution of this equation diverges monotonically because the coefficient on v_{t+1+i} has absolute value

$$\begin{aligned} \left| \bar{\theta} - \tau \int_{z^*+\Delta z}^1 (\theta - z^* - \Delta z) dF \right| &< \max \left\{ \bar{\theta}, \tau \int_{z^*+\Delta z}^1 (\theta - z^* - \Delta z) dF \right\} \\ &\leq \max \{ \bar{\theta}, \tau \bar{\theta} \} = \bar{\theta} < 1. \end{aligned}$$

Hence, the only admissible solution is obtained by setting v_{t+i} equal to its new steady-state value:

$$v_{t+i} = v_{t+1+i} = v^* + \Delta v = \frac{\delta A}{1 - \delta \bar{\theta} + \delta \tau \int_{z^*+\Delta z}^1 (\theta - z^* - \Delta z) dF}. \quad (23)$$

The new equilibrium investment level is then determined by the optimality condition for the capital goods producers, (10),

$$v_{t+i} \varphi'(I_{t+i}) = 1. \quad (24)$$

Because, by the previous argument, v_{t+i} is equal to its new steady-state equilibrium value, $v^* + \Delta v$, we have $I_{t+i} = I^* + \Delta I$ for all $i \geq 0$, where the sign of ΔI equals the sign of Δv . By substituting this value into the capital market clearing condition, (16) we obtain that the law of motion of the capital stock is now

$$k_{t+i+1} = \bar{\theta} k_{t+i} + \varphi(I^* + \Delta I)$$

for all $i \geq 0$, with $k_t = k^*$.

The dynamics of agents' consumption is given by the following equations:

$$c_{t+i} = A k_{t+i} - (I^* + \Delta I), \quad \text{for all } i \geq 0.$$

By substituting the values of k obtained from the law of motion of capital, we find that the change in consumption for a (marginal) change in z (and hence in

²³ We used here (9) and the property $1 + r_{t+i} = 1/\delta$, following from the specification of consumers' preferences, to simplify the expression.

²⁴ Note that expressions (21) and (22) give us the new equilibrium levels of q and v also for any discrete change Δz , as long as we have $v \geq q$, that is, as long as $z + \Delta z$ is not too close to zero.

v and I) is given by

$$\Delta c_t = -\Delta I,$$

$$\Delta c_{t+i} = \left\{ -1 + A \frac{1 - \bar{\theta}^i}{1 - \bar{\theta}} \varphi'(I^*) \right\} \Delta I, \quad \forall i \geq 1.$$

and hence the effect on agents' welfare is

$$\begin{aligned} \sum_{i=0}^{\infty} \delta^i \Delta c_{t+i} &= \left\{ \frac{1}{1-\delta} \left(-1 + A \frac{\delta}{1-\bar{\theta}} \varphi'(I^*) \right) - \sum_{i=1}^{\infty} (\delta \bar{\theta})^i A \frac{1}{1-\bar{\theta}} \varphi'(I^*) \right\} \Delta I \\ &= \left\{ -\frac{1}{1-\delta} + \left(A \frac{1}{1-\bar{\theta}} \varphi'(I^*) \right) \left(\frac{\delta}{1-\delta} - \frac{\delta \bar{\theta}}{1-\delta \bar{\theta}} \right) \right\} \Delta I. \end{aligned}$$

The term in brackets in this expression is strictly positive because, as we showed in the previous section, in a steady-state equilibrium we always have

$$A \frac{\delta}{1-\delta \bar{\theta}} > \frac{1}{\varphi'(I^*)} = v^*.$$

Hence, consumers' welfare increases if and only if $\Delta I > 0$.

From (23) it is then easy to verify that $\text{sign } \Delta v = \text{sign } \Delta z$, because

$$\frac{d}{dz^*} \int_{z^*}^1 (\theta - z^*) dF = - \int_{z^*}^1 dF < 0.$$

From (24) we obtain then

$$\frac{dI}{dz} = \frac{dv}{dz} \frac{dI}{dv} = \frac{dv}{dz} \left(-\frac{\varphi'}{v\varphi''} \right) > 0.$$

This establishes the following.

Proposition 7. The steady-state competitive equilibrium is constrained inefficient: a permanent increase in z above its equilibrium value is welfare improving.

The intervention is specified in terms of the threshold z below which the firm has to default on its debt. As argued in Section 4, a marginal increase of z^* corresponds to an increase in the firms' debt-equity ratio.

Proposition 7 establishes the optimality of a marginal increase in z . Consider then a sequence of discrete changes Δz , such that $z + \Delta z$ approaches 1. Along such a sequence, q goes to zero,²⁵ and we also see from (23) that v approaches

²⁵ Note that the equilibrium condition (21) has an admissible solution for all $z + \Delta z < 1$, but not in the limit for $z + \Delta z = 1$.

$\frac{\delta A}{1-\delta\theta}$, and hence, by (6), I approaches I_{FB} . That is, in the limit, the equilibrium corresponding to such an intervention converges to the steady-state, first-best allocation.²⁶ We can then say that the constrained optimal capital structure of firms exhibits maximal leverage.

To gain some understanding of the determinants of the above result, note first that, when firms increase their leverage, that is, z is increased above z^* , the tax paid on each unit of capital, $\tau \int_z^1 (\theta - z) dF$, decreases. At the same time, as we can see from the expression of the firms' market value in (13), firms face a higher probability of default and hence a higher expected capital loss in default, given by the difference between the liquidated value of the firm's assets, q , and the normal market value, v . At a competitive equilibrium, firms do not want to deviate from z^* as the private costs and benefits of a marginal increase in leverage offset each other. The private cost of default depends, however, on prices and, when all firms change their leverage choices, prices change. Once we substitute for q its equilibrium value from the market-clearing condition (9), as we did in (23), we find that the higher losses incurred by a firm when bankrupt are perfectly offset by the higher gains made when solvent (when the firm is able to buy capital at cheaper prices). As a consequence, when we take the change in prices into account, the net effect of an increase in z by all firms is just the decrease in the cost of the tax paid, and the firms' value v increases. Thus, once the pecuniary externality is internalized, the cost of debt financing is lower than the cost perceived by firms. Hence, a higher leverage induces a higher level of v . This in turn increases the firms' investment, which raises the capital stock in the economy. Because the equilibrium accumulation of capital is inefficiently low, as we noticed in Section 5.1, because of costs of equity and debt financing perceived by firms, the increase in investment and capital generates a welfare improvement.

The cost of bankruptcy as perceived by firms is a pure transfer, as the fire sale losses of bankrupt firms provide capital gains for the solvent firms. The same is true for the corporate income tax, in that case a transfer from solvent firms to consumers. Because the tax revenue is paid directly to households, one might think this has something to do with the fact that the tax reduces v . In fact, it crucially depends on how the tax revenues are paid out. Suppose the revenues from the tax were paid to firms instead of households. The distortion will remain as long as the transfers are lump sum, that is, not proportional to the firm's capital stock. A rational manager will perceive that an increase in the firm's capital stock increases its tax liability, but does not increase the transfer received, so he will still have an incentive to underinvest in equilibrium. Only if the transfer were proportional to the value of equity, that is, the tax base, would the distortionary effect disappear.

²⁶ In contrast, we see from (12), that when firms act as price takers their optimal decision when $q \rightarrow 0$ is $z \sim 0$.

It is important to note that our result on the welfare benefits of increasing firms' leverage does not depend on the absence of deadweight costs of bankruptcy. Suppose we were to assume that bankrupt firms lose a fraction $0 < \phi < 1$ of their output, consumed by the costs of the bankruptcy process. Each firm would take into account this additional cost of bankruptcy when choosing its optimal capital structure. The actual costs of bankruptcy for the firm (the costs once the pecuniary externality is internalized) in this case are positive, but it is still true that they are lower than the costs perceived by the firm, because the latter overestimate the costs of fire sales, due to the pecuniary externality. As a consequence, it remains true that increasing z^* will increase the value of capital v^* and as a result the level of investment and the capital stock will increase too. Because the equilibrium again exhibits underinvestment, such an increase in the investment level always increases welfare, as in the situation considered in this section.

But now an increase in z^* has another effect on welfare, going in the opposite direction, as it will also increase the deadweight costs of bankruptcy and hence reduce the resources that a given stock of capital generates for consumption. Which of the two effects dominates depends on the elasticity of investment with respect to v^* and hence z^* . In the Online Appendix, we replicate the analysis for the economy with deadweight costs of bankruptcy and show that, if the elasticity of investment with respect to v^* is sufficiently high, an increase in z^* is welfare improving because the increase in investment is sufficiently large relative to the increase in deadweight costs. Thus, the distortion caused by fire sales remains the crucial determinant of the welfare effects of an increase in firms' leverage.

6. Conclusion

We have analyzed the firms' capital structure choice in a dynamic general equilibrium economy with incomplete markets. Firms face a standard trade-off between the exemption of interest payments on debt from the corporate income tax and the risk of bankruptcy and fire sales. Fire sales are endogenously determined in equilibrium and arise from the illiquidity of the capital market in which the firm's assets are sold. When the corporate income tax rate is positive, we show that fire sales are an essential part of the equilibrium, the optimal capital structure is uniquely determined in equilibrium and firms' investment is lower than at its first-best level. Moreover, the debt to equity ratio chosen by firms is inefficiently low: a regulatory intervention inducing firms to increase their leverage generates an increase of firms' return to capital and hence also of their investment level and of consumers' welfare.

These findings highlight the importance of recognizing the presence of a pecuniary externality when firms evaluate the private cost of default due to fire sales. The sale of the assets of bankrupt firms at fire-sale prices clearly entails a loss for such firms, but constitutes, at the same time, a gain for solvent firms who

are so able to purchase capital cheaply. Our analysis shows that, by ignoring the effect of a higher leverage ratio on the fire-sale price of firms' assets, firms underestimate the benefits of these purchases and perceive the cost of debt as higher than reality. It is through such pecuniary externalities, concerning the price of liquidated assets, that interventions modifying the firms' capital structure affect welfare in general equilibrium when markets are incomplete.

We also demonstrate the robustness of our findings to the addition of deadweight costs of default given by the destruction of the firms' assets. As long as firms perceive the negative effect of these deadweight costs on their market value, they will still overestimate the costs of debt financing. Then an intervention increasing firms' leverage still increases investment. We can also think of environments in which there are deadweight costs of bankruptcy that firms do not take into account. These might include costs imposed on other firms because of the disruption of the financial system.²⁷ The presence of deadweight external costs of bankruptcy will tend to reduce the constrained-efficient level of leverage relative to the equilibrium level. Whether the constrained-efficient level of leverage is higher or lower than the equilibrium level will depend on the strength of the two externalities, the one that represents a social cost and one that does not.

Although the model we have studied deals with corporate debt, the results are suggestive for the current debate about the funding and capital structure of financial institutions in the wake of the financial crisis. A similar exercise for financial institutions would seem to be an important topic for future research.

In the rest of this section, we briefly discuss the sensitivity of our results to some of the features of the model.

A special feature of our model is the fact that the shocks affecting firms are purely idiosyncratic and there is no aggregate risk. There has been a lot of interest in the macroeconomic literature regarding the role of financial frictions in the propagation of economic shocks. A large and influential stream of this literature concerns the financial accelerator. In this literature, mentioned in the Introduction, firms' financing plays an important role. Because of moral hazard problems, firms' ability to borrow is limited by the value of equity or of the assets that serve as collateral. A negative shock to the value of equity and collateral reduces the firms' ability to borrow for investment and this in turn propagates through the cycle. In recent papers (Gertler and Kiyotaki 2010), the focus has been shifted to the role of banks and the way in which fluctuations in bank capital restrict lending and propagate business-cycle disturbances.

Our focus, unlike this macroeconomic literature, is on questions of efficiency and regulation, rather than business-cycle dynamics. Extending the analysis to include aggregate uncertainty would make the model less tractable, but we

²⁷ Also, in Lorenzoni (2008) and some of the other papers mentioned in the Introduction the capital of bankrupt firms can only be sold to different types of firms who operate a less productive technology, hence there is a deadweight cost attached to fire sales.

believe it would not change the fundamental qualitative features of the results we obtained. Suppose, for example, that we introduce an additional, aggregate shock affecting the depreciation of firms' capital: each unit of capital used by firm i at date t is reduced, after production of the consumption good, to $s_t \theta_{it}$ units, where s_t is a common shock and s_t and θ_{it} are independent.²⁸ The law of motion of capital becomes

$$k_{t+1} = s_t \bar{\theta} k_t + \varphi(I_t),$$

and hence the accumulation of capital is now stochastic.

In this simple environment, under the maintained risk neutrality assumption, both the equilibrium value of liquidated capital q and the market value of capital v decrease with the magnitude of the shock s whereas the firms' capital structure, as described by z , is not affected by s . Also, the pecuniary externality is still present, leading firms to overestimate the cost of bankruptcy and debt financing and choose too little debt in the equilibrium capital structure. The introduction of risk aversion may generate additional affects. For example, an increase in the use of debt financing might increase the volatility of prices, which could have a negative effect on the welfare of risk averse individuals. On the other hand, because firms take into account the effect of risk on consumers' valuation of their plans, at the margin it is not clear that this effect will dominate the pecuniary externality. An answer to this question would require a proper quantitative analysis and is a matter for further research.

More generally, the extension of the model to allow for aggregate risk could offer some interesting implications for the properties of the equilibrium prices of debt and equity, as well as for the pattern of consumption and investment over the business cycle. The effects of aggregate uncertainty on the firms' choice of capital structure are also of interest. We plan to pursue these issues in future work.

In our stylized model, there is only one technology for producing consumption goods. The only choice for the firms in the consumption goods sector is how to finance their purchases of capital goods. In particular, they have no control over the riskiness of the production technology. This may be seen as a limitation, because in practice firms may be able to diversify their business lines to reduce the risk of default. To test the robustness of our results, it is then useful to consider an extension of the analysis in which an alternative, safe technology can be used to produce consumption goods using capital goods. The safe technology is subject to a nonstochastic depreciation rate $1 - \bar{\theta}$, but has a lower productivity $B < A$.

We can interpret the safe technology as a way to provide liquidity in the economy. It allows firms to make capital gains from the purchase of assets in fire sales whenever liquidity is scarce in the system. It can be shown²⁹

²⁸ See the Online Appendix for a formal analysis of this case and the derivation of some properties of equilibria.

²⁹ The details are in the Online Appendix.

that in equilibrium firms will specialize in one of the technologies. There proves to be, in fact, no advantage to combining the safe and risky technology. More interestingly, we find that introducing the safe technology does little to mitigate the inefficiency: on the contrary, it generates an additional source of inefficiency and, as long as B is not too high, it reduces welfare. Although the presence of firms using the safe technology reduces the scale of the fire sales and raises the price of liquidated assets, it reduces the returns to capital and hence the incentives to invest. The mechanism generating the inefficiency is now somewhat different: the introduction of a safe technology diverts the capital gains from purchases at fire-sale prices to the firms choosing the safe, but less productive, technology, thus depriving the firms choosing the risky technology of some of those gains.

Appendix

Proof of Proposition 1. From the strict concavity of φ and the gradient inequality, it follows that, for any $k < \hat{k}$,

$$\begin{aligned}\varphi(Ak) &\leq \varphi(A\hat{k}) + \varphi'(A\hat{k})A(k - \hat{k}) \\ &= (1 - \bar{\theta})\hat{k} + \varphi'(A\hat{k})A(k - \hat{k}) \\ &< (1 - \bar{\theta})\hat{k}.\end{aligned}$$

Hence,

$$\varphi(Ak) + \bar{\theta}k < (1 - \bar{\theta})\hat{k} + \bar{\theta}k < \hat{k}.$$

For any $k > \hat{k}$,

$$\begin{aligned}\varphi(Ak) &\leq \varphi(A\hat{k}) + \varphi'(A\hat{k})A(k - \hat{k}) \\ &< (1 - \bar{\theta})\hat{k} + (1 - \bar{\theta})(k - \hat{k}) \\ &= (1 - \bar{\theta})k,\end{aligned}$$

where the second inequality follows from the assumptions made on $\varphi(\cdot)$, implying the existence of a unique solution for \hat{k} . Thus,

$$k_t > \hat{k} \implies k_{t+1} < k_t$$

and

$$k_t < \hat{k} \implies k_{t+1} < \hat{k}.$$

Proof of Proposition 2. At an optimal steady state the multipliers $\{(\lambda_t^*, \mu_t^*)\}_{t=0}^\infty$ satisfy

$$\lambda_t^* = \delta^t u'(c^*) = \delta^t \lambda_0^*,$$

and hence

$$\mu_t^* = \frac{\lambda_t^*}{\varphi'(I^*)} = \frac{\delta^t \lambda_0^*}{\lambda_0^* / \mu_0^*} = \delta^t \mu_0^*,$$

for every t . The first-order conditions for the steady-state optimum can then be written as

$$u'(c^*) = \lambda_0^*, \quad (\text{A1})$$

$$\delta \lambda_0^* A + \delta \mu_0^* \bar{\theta} = \mu_0^*, \quad (\text{A2})$$

$$\mu_0^* \varphi'(I^*) = \lambda_0^*. \quad (\text{A3})$$

Conditions (A2) and (A3) can be rewritten as

$$\frac{\delta A}{1 - \delta \bar{\theta}} = \frac{\mu_0^*}{\lambda_0^*} = \frac{1}{\varphi'(I^*)}. \quad (\text{A4})$$

The feasibility conditions become

$$c^* + I^* = Ak^*$$

and

$$k^* = \bar{\theta} k^* + \varphi(I^*).$$

Thus,

$$k^* = \frac{\varphi(I^*)}{1 - \bar{\theta}},$$

where I^* is determined by (A4).

Proof of Proposition 4. The derivative of the expression in (13) with respect to z_{t+1} is easily calculated to be

$$\begin{aligned} & \frac{1}{1+r_t} \left\{ (A + q_{t+1} z_{t+1}) f(z_{t+1}) - v_{t+1} \left(\frac{A}{q_{t+1}} + z_{t+1} \right) f(z_{t+1}) + \right. \\ & \quad \left. \tau v_{t+1} (z_{t+1} - z_{t+1}) f(z_{t+1}) + \tau v_{t+1} (1 - F(z_{t+1})) \right\} \\ & = \frac{1}{1+r_t} \left\{ \left(1 - \frac{v_{t+1}}{q_{t+1}} \right) A f(z_{t+1}) + \left(1 - \frac{v_{t+1}}{q_{t+1}} \right) q_{t+1} z_{t+1} f(z_{t+1}) + \tau v_{t+1} (1 - F(z_{t+1})) \right\}. \end{aligned}$$

The first-order condition for an interior solution of the firm's problem requires this expression to equal zero, a condition that can be written as

$$\left(\frac{v_{t+1}}{q_{t+1}} - 1 \right) (A + q_{t+1} z_{t+1}) f(z_{t+1}) = \tau v_{t+1} (1 - F(z_{t+1})),$$

or

$$\left(\frac{1}{q_{t+1}} - \frac{1}{v_{t+1}} \right) (A + q_{t+1} z_{t+1}) \frac{f(z_{t+1})}{1 - F(z_{t+1})} = \tau.$$

A solution to this equation, if it exists, is unique because all terms on the left-hand side are positive and increasing in z_{t+1} . The term $A + q_{t+1} z_{t+1}$ is in fact clearly increasing in z_{t+1} , and so is $\frac{f(z_{t+1})}{1 - F(z_{t+1})}$ under the assumption of an increasing hazard rate.

From the above expression, we then see that when $\left(\frac{1}{q_{t+1}} - \frac{1}{v_{t+1}} \right) A f(0) \geq \tau$, we have a corner solution with $z_{t+1} = 0$. In contrast, when $\left(\frac{1}{q_{t+1}} - \frac{1}{v_{t+1}} \right) A f(0) < \tau$ and $q_{t+1} < v_{t+1}$, it is easy to verify that a corner solution with $z_{t+1} = 1$ never exists. By the continuity of the objective function in z_{t+1} , a solution always exists, so it follows that an interior solution exists.

A.1 Market Clearing in the Securities Market. The value of debt and equity issued by each firm at any t is equal to the market value of depreciated capital, $v_t \bar{\theta} k_t$, plus the value of newly produced capital goods, $v_t \varphi(I_t)$. To find the consumer's savings, we need to first find the value of the consumer's wealth in subperiod C of date t . This is equal to the sum of the profits from the capital good sector, the proceeds from the liquidation of firms that defaulted in this period, and the value of the firms that did not default in the period minus the corporation tax plus the lump sum transfer from the government. The corporation tax and the transfer cancel in equilibrium, and the consumer's wealth, w_t , is given by

$$w_t = v_t \varphi(I_t) - I_t + \int_0^{z_t} (A + q_t \theta_t) k_t dF + \int_{z_t}^1 v_t \left(\frac{A}{q_t} + \theta_t \right) k_t dF.$$

Using the market-clearing condition in the liquidation market (9), this simplifies to:

$$w_t = v_t \varphi(I_t) - I_t + A k_t + v_t \bar{\theta} k_t.$$

Therefore, the securities market clears at date t if

$$\begin{aligned} w_t - c_t &= v_t \varphi(I_t) - I_t + A k_t + v_t \bar{\theta} k_t - c_t \\ &= v_t (\bar{\theta} k_t + \varphi(I_t)) \end{aligned}$$

or

$$c_t + I_t = A k_t.$$

So market clearing in the consumption goods market (15) implies market clearing in the securities markets, as claimed.

Proof of Proposition 5. Equations (18) and (20) come directly from conditions 4 and 2 of the definition of competitive equilibrium, applied to a steady state. From the equation specifying the law of motion of the value of the firm, using the fact that at a steady state $1/(1+r^*) = \delta$, we then get

$$\begin{aligned} v^* &= \delta \left\{ \int_0^{z^*} (A + q^* \theta) dF + \int_{z^*}^1 \left(\frac{v^*}{q^*} (A + q^* \theta) - \tau v^* (\theta - z^*) \right) dF \right\} \\ &= \delta \left\{ \int_0^{z^*} \left(A + v^* \theta - \left(\frac{v^*}{q^*} - 1 \right) q^* \theta \right) dF + \int_{z^*}^1 \left(A + v^* \theta + \left(\frac{v^*}{q^*} - 1 \right) A - \tau v^* (\theta - z^*) \right) dF \right\} \\ &= \delta \left\{ A + v^* \bar{\theta} - \int_{z^*}^1 \tau v^* (\theta - z^*) dF \right\}, \end{aligned}$$

where in the last step we used (18) to simplify the expression. Solving for v , we get:

$$v^* = \frac{\delta A}{1 - \delta \bar{\theta} + \tau \delta \int_{z^*}^1 (\theta - z^*) dF},$$

that is, Equation (19).

Let $v(z^*)$ denote the solution of Equation (19) with respect to v and let $q(z^*)$ denote the solution of (18) with respect to q . Note that $v(z^*)$ is a strictly increasing, and $q(z^*)$ is a strictly decreasing function of z^* . The remaining condition (20) can then be written as

$$\left(1 - \frac{q(z^*)}{v(z^*)} \right) \left(\frac{A}{q(z^*)} + z^* \right) \frac{f(z^*)}{1 - F(z^*)} = \tau, \quad (\text{A5})$$

and it is clear from inspection that all the terms on the left-hand side are increasing in z^* , so there exists at most one solution, that is one steady state.

To see that there exists a solution to (A5), note that as $z^* \rightarrow 0$, $q(z^*) \rightarrow \infty$, and $v(z^*) \rightarrow \frac{\delta A}{1 - \delta \bar{\theta} + \tau \delta \bar{\theta}}$, so for some finite value $z^* > 0$, we have $q(z^*) = v(z^*)$ and the left-hand side of (A5) equals zero. Next, consider what happens as $z^* \rightarrow 1$ and note that $q(z^*) \rightarrow 0$ and $v(z^*) \rightarrow \frac{\delta A}{1 - \delta \bar{\theta}} > 0$, so the left-hand side of (A5) is positive and arbitrarily large. Thus, by continuity, there exists a value of $0 < z^* < 1$ satisfying (A5).

Proof of Proposition 6. Consider first the effects of a change in τ or δ . From Equation (18), it is clear that the solution $q(z^*)$ is independent of τ and δ , whereas the solution of Equation (19) $v(z^*, \tau, \delta)$ is decreasing in τ and increasing in δ . Substituting into (A5)

$$\left(1 - \frac{q(z^*)}{v(z^*, \tau, \delta)}\right) \left(\frac{A}{q(z^*)} + z^*\right) \frac{f(z^*)}{1 - F(z^*)} = \tau, \quad (\text{A6})$$

we see that an increase in τ increases the right-hand side, and by decreasing $v(z^*, \tau, \delta)$, it decreases the left-hand side. Thus, for the above condition to be satisfied, the left-hand side must be increased and that requires an increase in z^* . Thus, an increase in τ increases z^* and, hence, reduces $q^* = q(z^*)$. Because $v(z^*, \tau, \delta)$ is increasing in z^* and decreasing in τ , the net effect on v^* (and hence the effect on I^* and k^*) is uncertain. From Equation (19), we can say that v^* (and hence I^* and k^*) will increase if the tax revenue $\tau \int_{z^*}^1 (\theta - z^*) dF$ declines as a result of the increase in τ .

Now consider the impact of an increase in δ . An increase in δ will increase $v(z^*, \tau, \delta)$ and hence increase the term on the left-hand side of (A6). For Equation (A6) to hold, z^* must decrease to ensure the left-hand side stays constant. This implies that q^* increases. The overall effect on v of the decrease in z^* and increase of δ , because the term on the left-hand side of (A6) must stay constant for (20) to hold, is that v increases (actually more than q). Hence, I^* and k^* also increase.

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